

## SPECIFICATION

## ELECTROMAGNETIC PUMP

## FIELD OF TECHNOLOGY

The present invention relates to an electromagnetic pump, more precisely relates to a compact electromagnetic pump used for sending a fluid, e.g., gas, liquid.

## BACKGROUND TECHNOLOGY

The inventor of the present invention invented a small and thin electromagnetic pump, wherein a moving member made of a magnetic material is reciprocally moved in a cylinder of a stator, pump chambers are respectively formed between both end faces of the cylinder and both side faces of the moving member extended in the moving direction thereof, electromagnetic coils are fitted around periphery of the cylinder, a fluid is introduced into one of the pump chambers from outside via a first valve and discharged outside via a second valve by applying electricity to the electromagnetic coils, and the fluid is introduced into and discharged from the other pump chamber by the same manner (see Patent Document 1). In Fig. 11, magnetic fluxes generated from an N-pole of a magnet 103 of the moving member 101 form a magnetic circuit to an S-pole of the magnet 103 via an inner yoke 104a, an outer yoke 105 and an inner yoke 104b. By applying electricity to electromagnetic coils 106a and 106b, an electromagnetic force is applied to the electromagnetic coils 106a and 106b from the magnetic field, but the electromagnetic coils 106a and 106b are fixed to the stator 101 so that the moving member 102 is moved in the axial direction (in the vertical direction in Fig. 11) as a counteraction.

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In the above described electromagnetic pump, a normal or abnormal motion of the moving member 101, which is accommodated in a cylinder section

109 whose both ends are closed by frames 107 and 108, and a normal or abnormal movable range of the moving member 101 are detected by various manners. For example, as shown in Fig. 11, the motion of the moving member 101 is detected by a magnetic sensor (e.g., hall element) 110 provided outside of the lower frame 108. The magnetic sensor 110 detects leakage fluxes generated by the magnet 103 of the moving member 101, so that operating positions of the moving member 101 can be detected.

## DISCLOSURE OF THE INVENTION

### PROBLEMS TO BE SOLVED BY THE INVENTION

In the electromagnetic pump shown in Fig. 11, the moving member 101 is accommodated in the cylinder section 109 closed by the frames 107 and 108, so the magnetic sensor 110 cannot be located close to the moving member 101. Magnetic flux density leaked from the moving member 101 is small; if the magnetic sensor 110 is located at a position separated away from the moving member 101, a size of the pump must be large, further magnetic flux density detected by the magnetic sensor 110 must be further small so that variation of magnetic flux density cannot be detected. For example, if the magnetic sensor 110 is provided to one of the frames 107 and 108, variation of magnetic flux density is always detected in one direction, so polarity reversal caused by the reciprocating motion of the moving member 101 is not detected and sensitivity of the sensor must be limited.

The magnetic sensor 110 is easily influenced by magnetic fields produced by the electromagnetic coils 106a and 106b. Namely, a cycle time of the reciprocating motion of the moving member 101 is equal to that of variation of magnetic flux density leaked from the moving member 101. Further, a magnetizing cycle time of the electromagnetic coils is also equal. Therefore, it is difficult to judge if the variation of magnetic flux density detected by the magnetic sensor is caused by the reciprocating motion of the moving member

101 or magnetization of the electromagnetic coils 106a and 106b.

The present invention has invented to solve the above described problems, and an object is to provide an electromagnetic pump capable of highly precisely detecting operating positions of a moving member without enlarging the pump and minimizing influence of magnetic field produced by supplying electricity to an electromagnetic coil.

To achieve the object, the present invention has following structures.

The electromagnetic pump comprises: a cylinder; a moving member being movably accommodated in the cylinder, the moving member having a permanent magnet; an air-core electromagnetic coil being fitted around the cylinder, the electromagnetic coil reciprocally moving the moving member in the axial direction when electricity is supplied to the coil; and pump chambers for sending a fluid, the pump chambers being formed in the cylinder, said pump is characterized in that an air-core detecting coil for detecting reciprocating motion of the moving member is fitted around the cylinder so as to be coaxial with the electromagnetic coils.

In the electromagnetic pump, a plurality of the electromagnetic coils may be fitted around the periphery of the cylinder, and the detecting coils may be respectively provided close to axial end faces of the electromagnetic coils.

In the electromagnetic pump, yokes made of a magnetic material may be provided to axial end faces of the detecting coil or the axial end faces and an outer circumferential face thereof.

In the electromagnetic pump, frequency of induced voltage of the detecting coil may be twice as high as frequency of the reciprocating motion of the moving member.

In the electromagnetic pump, flow volume of the pump may be detected on the basis of the induced voltage detected by the detecting coil; flow volume of the pump greater than a prescribed value or not may be detected on the basis of a threshold value of the induced voltage detected by the detecting coil; a normal or

abnormal reciprocating motion of the moving member may be detected on the basis of a threshold value of the induced voltage detected by the detecting coil; and motion of the moving member may be controlled on the basis of a threshold value of the induced voltage detected by the detecting coil.

Further, the induced voltage detected of the detecting coil may be detected in a detection range, in which variation of the induced voltage caused by magnetization of the electromagnetic coil is small.

## EFFECTS OF THE INVENTION

In the electromagnetic pump of the present invention, the air-core detecting coil for detecting reciprocating motion of the moving member is fitted around a periphery of the cylinder, in which many magnetic fluxes leak from the moving member, and coaxial with electromagnetic coils, so that the induced voltage of the detecting coil caused by the reciprocating motion of the moving member 101 can be increased, detecting accuracy can be improved and the motion of the moving member can be detected without enlarging the pump.

If the yokes made of the magnetic material are provided to the axial end faces and the outer circumferential face of the detecting coil, number of magnetic fluxes, which are generated from the moving member and which interlink the detecting coil, can be increased, so that the induced voltage of the detecting coil can be increased and detecting sensitivity can be improved.

If the frequency of the induced voltage of the detecting coil is twice as high as that of the reciprocating motion of the moving member, the frequency can be twice as high as that of a magnetic field produced by the electromagnetic coil, whose magnetizing frequency is equal to the frequency of the reciprocating motion of the moving member; the variation of magnetic flux density caused by the reciprocating motion of the moving member and the variation of magnetic flux density caused by the magnetization of the electromagnetic coil can be easily distinguished.

Further, the reciprocating motion of the moving member and the flow volume of the pump can be detected on the basis of the induced voltage of the detecting coil, and the motion of the moving member can be controlled.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a sectional view of an electromagnetic pump relating to the present invention.

Fig. 2 is a partial sectional view of Example 1 of the electromagnetic pump.

Fig. 3 is an explanation view of magnetic fluxes working to a detecting coil, wherein a moving member is moved.

Fig. 4 is an explanation view of magnetic fluxes working to the detecting coil, wherein the moving member is moved.

Fig. 5 is an explanation view of magnetic fluxes working to the detecting coil, wherein the moving member is moved.

Fig. 6 is a partial sectional view of Example 2 of the electromagnetic pump.

Fig. 7 is graphs relating to Example 3 of the electromagnetic pump.

Fig. 8 is graphs relating to Example 3 of the electromagnetic pump.

Fig. 9 is graphs relating to Example 4 of the electromagnetic pump.

Fig. 10 is graphs relating to Example 4 of the electromagnetic pump.

Fig. 11 is a partial sectional view of the moving member of the conventional electromagnetic pump.

#### PREFERRED EMBODIMENTS OF THE INVENTION

The preferred embodiments of the stator of the present invention will be explained with reference to the accompanying drawings. In the electromagnetic pump of the present embodiment, a moving member having a permanent magnet is accommodated in a cylinder, air-core electromagnetic coils are fitted around the cylinder, and the moving member is reciprocally moved in the axial direction by supplying electricity to the electromagnetic coils so as to send a fluid from

pump chambers formed in the cylinder.

A typical structure of the electromagnetic pump will be explained with reference to Fig. 1. A moving member 10 is accommodated in a closed cylinder and capable of reciprocally moving in the axial direction of the cylinder. The moving member 10 is constituted by a disk-shaped magnet 12 and a pair of inner yokes 14a and 14b, which sandwich the magnet 12 in the thickness direction. The magnet 12 is a permanent magnet magnetized in the thickness direction (the vertical direction in Fig. 1), and one of surfaces of the magnet is an N-pole, the other surface is an S-pole. The inner yokes 14a and 14b are made of a magnetic material, and each of the inner yokes 14a and 14b comprises a plate section 15a, whose diameter is slightly greater than that of the magnet 12, and a flange section 15b, which is vertically extended from an edge of the plate section 15a like a short cylinder. Outer circumferential faces of the flange sections 15b act as magnetic flux working surfaces of the moving member 10, and magnetic fluxes generated by the magnet 12 work therefrom.

A closing member 16, which is made of a nonmagnetic material, e.g., plastic, covers an outer circumferential face of the magnet 12.

The closing member 16 covers the magnet 12 so as to prevent the magnet 12 from exposing and rusting and integrates the magnet 12 with the inner yokes 14a and 14b. The closing member 16 fills an outer periphery of the magnet 12, which is sandwiched by the inner yokes 14a and 14b, but an outer diameter of the closing member 16 is slightly shorter than those of the inner yokes 14a and 14b. By employing that closing member 16, the closing member 16 does not contact a grinding blade so that outer circumferential faces of the inner yokes 14a and 14b can be finished without damaging the grinding blade; and reduction of a space between the moving member 10 and the cylinder, which is caused by thermal expansion of the closing member 16 when the pump is used at high temperature, can be prevented even if a thermal expansion coefficient of the closing member 16 is greater than those of the inner yokes 14a and 14b, so that the pump can be

stably operated.

Next, a stator of the electromagnetic pump will be explained with reference to Fig. 1. An upper frame 20a and a lower frame 20b, which are made of a nonmagnetic material, constitute the cylinder, and the moving member 10 is movably accommodated in the cylinder as described above. In the present embodiment, a cylindrical section 24 is integrated with a frame body 22b of the lower frame 20b. An upper end of the cylindrical section 24 is fitted in a groove 28, which is formed in a frame body 22a of the upper frame 20a, so that the cylinder, whose axial end faces are closed by the frames 20a and 20b, can be formed. A sealing member 29, which is provided in the groove 28, contacts the upper end of the cylindrical section 24, so the inner space of the cylinder can be tightly sealed by making the upper end of the cylindrical section 24 contact the sealing member 29. Note that, the cylindrical section 24 may be extended from the upper frame 20a and fitted with the lower frame 20b. Further, the cylindrical section 24 may be separated from the lower frame 20b or the upper frame 20a.

As described above, the axial end faces of the cylinder are closed by the frames 20a and 20b, and pump chambers 30a and 30b are respectively formed between inner faces of the frames 20a and 20b and both side faces of the moving member 10 extended in the moving direction thereof. The pump chambers 30a and 30b respectively correspond to spaces formed between both surfaces of the moving member 10 and the frame bodies 22a and 22b of the frames 20a and 20b. The moving member 10 slides on the inner face of the cylinder with air-tightly or liquid-tightly sealing the cylindrical section 24. To smoothly slide the moving member 10, the outer circumferential face of the inner yokes 14a and 14b are coated with a lubricative and rust-resistant coating agent. Further, means for preventing rotation of the moving member 10 may be provided.

Dampers 32 are provided to the end faces (inner faces) of the frame bodies 22a and 22b. The dampers 32 absorb shocks when the inner yokes 14a and 14b contact the end faces of the frame bodies 22a and 22b at end positions of a

movable range of the moving member 10. Note that, the dampers 32 may be provided to end faces of the inner yokes 14a and 14b, which contact the frame bodies 22a and 22b, instead of the end faces of the frame bodies 22a and 22b.

An inlet valve 34a and an outlet valve 36a are provided in the frame body 22a of the upper frame 20a and connected to the pump chamber 30a. An inlet valve 34b and an outlet valve 36b are provided in the frame body 22b of the lower frame 20b and connected to the pump chamber 30b.

Inlet paths 38a and 38b are respectively formed in the frames 20a and 20b and connected to the valves 34a and 34b. Outlet paths 40a and 40b are respectively formed in the frames 20a and 20b and connected to the valves 36a and 36b. The path 38a of the upper frame 20a is connected to the path 38b of the lower frame 20b via a connection tube 42; the path 40a of the upper frame 20a is connected to the path 40b of the lower frame 20b via a connection tube 44. With this structure, the inlet paths and the outlet paths of the frames 20a and 20b are respectively connected to one inlet port 38 and one outlet port 40.

In Fig. 1, air-core electromagnetic coils 50a and 50b are fitted around the periphery of the cylinder. The electromagnetic coils 50a and 50b are slightly separated in the axial direction of the cylinder and symmetrically arranged with respect to the axial line of the cylinder. Axial lengths of the electromagnetic coils 50a and 50b are longer than moving strokes of the flange sections 15b of the inner yokes 14a and 14b. The electromagnetic coils 50a and 50b are wound in the opposite directions, and electricity is supplied from one electric source so that electric currents run in the opposite directions. Since the electromagnetic coils 50a and 50b are wound in the opposite directions, forces working to the electric currents running through the electromagnetic coils 50a and 50b, which interlink with the magnetic fluxes of the magnet 12, are combined, and the combined force works to the moving member 10 as a counter force or a thrust force.

An outer yoke 52 encloses the electromagnetic coils 50a and 50b. The outer yoke 52 is made of a magnetic material so as to increase number of

magnetic fluxes interlinking the electromagnetic coils 50a and 50b and effectively work an electromagnetic force to the moving member 10. Since the flange sections 15b are extended from the edges of the inner yokes 14a and 14b, which constitute the moving member 10, in the axial direction, magnetic resistance of a magnetic circuit, which is formed from the magnet 12 to the outer yoke 52 via the inner yokes 14a and 14b, can be reduced. With this structure, total number of magnetic fluxes from the moving member 10 can be increased (the magnetic circuit for passing magnetic fluxes can be securely formed), magnetic fluxes generated by the magnet 12 can be interlinked with the electric currents running through the electromagnetic coils 50a and 50b at a right angle so that a thrust force for moving the moving member 10 in the axial direction can be effectively generated. Further, mass of the moving member 10 is lower with respect to the thrust force, so that fast response can be performed and flow volume can be increased.

When the frames 20a and 20b are fitted together, the electromagnetic coils 50a and 50b and the outer yoke 52 can be coaxially arranged by fitting the outer yoke 52 in the grooves 28 of the frames 20a and 20b.

When an alternate current is supplied to the electromagnetic coils 50a and 50b, the moving member 10 is reciprocally moved (in the vertical direction) by electromagnetic forces generated by the electromagnetic coils 50a and 50b. Since the electromagnetic forces generated by the electromagnetic coils 50a and 50b move the moving member 10 in one direction and the opposite direction according to the directions of the electric current running through the electromagnetic coils 50a and 50b, the moving member 10 can be reciprocally moved with optional stroke by controlling time of supplying electricity to the electromagnetic coils 50a and 50b and the directions of the electric current running therethrough with a control section, not shown. When the moving member 10 contacts the inner faces of the frame bodies 22a and 22b, the shocks can be absorbed by the dampers 32.

The pumping action of the electromagnetic pump is performed by reciprocally moving the moving member 10 by the electromagnetic coils 50a and 50b, so that a fluid is alternately introduced into and discharged from the pump chambers 30a and 30b. Namely, in Fig. 1, when the moving member 10 is moved downward, the fluid is introduced into the pump chamber 30a; simultaneously, the fluid is discharged from the pump chamber 30b. On the other hand, when the moving member 10 is moved upward, the fluid is discharged from the pump chamber 30a; simultaneously, the fluid is introduced into the pump chamber 30b. Even if the moving member 10 is moved in any directions, the fluid is introduced and discharged, so that pulsation of the fluid can be restricted and the fluid can be sent efficiently.

In the electromagnetic pump of the present embodiment, the moving member 10 includes the inner yokes 14a and 14b having the flange sections 15b, and the inlet valves 34a and 34b and the outlet valves 36a and 36b are located close to the end faces of the moving member 10, so that the thin and compact pump can be produced. For example, a height of the electromagnetic pump is about 15 mm, and a width thereof is about 20 mm.

The electromagnetic pump of the present embodiment can be used for sending any kinds of fluid, e.g., gas, antifreeze liquid. In case of using the pump as a liquid pump, if the pump has one moving member 10 and its sending pressure is low, a plurality of the moving members 10, each of which is constituted by the magnet 12 and the inner yokes 14a and 14b, may be used as a coupled moving member. By coupling a plurality of the moving members, a greater thrust force can be gained so that the electromagnetic pump having a prescribed sending pressure can be produced.

#### EXAMPLE 1

A structure and action of a detecting section, which detects the reciprocating action of the moving member of the electromagnetic pump, will be

explained with reference to Figs. 2-5. In Fig. 2, an air-core detecting coil 53 for detecting the reciprocating motion of the moving member 10 is fitted around the cylinder and coaxial with the electromagnetic coil 50a and 50b. For example, the detecting coil 53 encloses the cylinder and is sandwiched between the axial ends of the electromagnetic coil 50a and 50b.

Magnetic fluxes from the moving member 10 to the detecting coil 53 vary according to the positions of the moving member 10 as shown in Figs. 3-5. Note that, Fig. 3 shows the moving member 10 located at an upper position; Fig. 4 shows the moving member 10 located at an intermediate position; and Fig. 5 shows the moving member 10 located at a lower position. Number of magnetic fluxes interlinking the detecting coil 53 is maximized when the moving member 10 is located at the intermediate position (see Fig. 4); number of magnetic fluxes interlinking the detecting coil 53 is minimized when the moving member 10 is located at the upper and lower positions (see Figs. 3 and 5). The moving member 10 repeats the reciprocating motion as shown in Fig. 3→Fig. 4→Fig. 5→Fig. 4→Fig. 3. While the moving member 10 reciprocally moved, two cycles of variation of the number of magnetic fluxes interlinking with the detecting coil 53 occurs. Therefore, two cycles of induced voltage is generated in the detecting coil 53. Note that, the detecting action of the detecting coil 53 may be performed while the moving member 10 is moved between the positions shown in Figs. 3 and 4 or while the moving member 10 is moved between the positions shown in Figs. 4 and 5. In this case, one cycle of the induced voltage is generated in the detecting coil 53 while the moving member 10 goes and returns once. Note that, the inner yokes 14a and 14b of the moving member 10 may be omitted.

## EXAMPLE 2

Another example of the detecting section, which detects the reciprocating action of the moving member of the electromagnetic pump, will be explained with reference to Fig. 6. The structural elements shown in Fig. 2 are assigned the

same symbols and explanation will be omitted. In Fig. 6, the detecting coil 53 for detecting the reciprocating motion of the moving member 10 is fitted around the cylinder and sandwiched between the axial ends of the electromagnetic coil 50a and 50b as well as the former example. In the present example, two yokes 26a and 26b, which are made of a magnetic material, are respectively provided on the axial end faces of the detecting coil 53; an outer yoke 52 is provided on an outer circumferential face of the detecting coil 53. With this structure, a magnetic circuit, through which magnetic fluxes generated by the moving member 10 pass, is formed by the yoke 26a, the outer yoke 52 and the yoke 52b. Therefore, the number of magnetic fluxes, which are generated by the moving member 10 and which interlink with the detecting coil 53, can be increased, so that the induced voltage of the detecting coil 53 can be increased and detecting sensitivity can be improved. Note that, if the yokes 26a and 26b are respectively provided on the axial end faces of the detecting coil 53, the outer yoke 52 may be omitted.

### EXAMPLE 3

An example for detecting flow volume of the electromagnetic pump on the basis of the reciprocating motion of the moving member will be explained with reference to Figs. 7 and 8. The structural elements shown in Fig. 2 are assigned the same symbols and explanation will be omitted. The present example is characterized in that the flow volume of the pump is detected on the basis of the induced voltage detected by the detecting coil 53. Namely, multiplying the speed “V” of the reciprocating motion of the moving member 10 by the sectional area “S” of the moving member 10 gives the flow volume of the pump. When the speed “V” of the moving member 10 is increased, the flow volume of the pump is increased so that the induced volume detected by the detecting coil is increased. According to Fig. 7, the flow volume of the pump can be known on the basis of amplitude of the induced voltage of the detecting coil 53.

According to Fig. 8, a user can know if the moving member 10 performs

the reciprocating motion or not by setting a threshold value of the induced voltage detected by the detecting coil 53. Namely, the threshold value of the induced voltage of the detecting coil 53, which corresponds to a prescribed flow volume, is set. The detected induced voltage is compared with the threshold value by comparing means, e.g., comparator, and converted into pulse signals. If the flow volume is greater than the prescribed volume, the pulse signals are generated; if the flow volume is smaller than the prescribed volume, no pulse signals are generated. When a control section controls voltage, current intensity, frequency, etc. of the electromagnetic coils 50a and 50b, if the maximum amplitude or the minimum amplitude of the induced voltage of the detecting coil 53, which is detected when the moving member 10 is normally moved, is used as the threshold value, the user can know if the moving member 10 of the pump is normally moved or not.

#### EXAMPLE 4

An example for controlling the moving member of the electromagnetic pump will be explained with reference to Figs. 9 and 10. The structural elements shown in Fig. 2 are assigned the same symbols and explanation will be omitted. The present example is characterized in that the motion of the moving member 10 is controlled on the basis of the induced voltage detected by the detecting coil 53. A control section, now shown, performs feedback control so as to normally move the moving member 10, so that the flow volume of the pump and the electricity supplied to the electromagnetic coils 50a and 50b can be suitably controlled, further the movable range of the moving member 10 can be suitably controlled so as not to collide with the frame bodies 22a and 22b.

In a desired voltage range of the induced voltage, variation of the induced voltage, which is caused by magnetizing the electromagnetic coils 50a and 50b, should be small. Since the electromagnetic coils 50a and 50b are respectively provided on the upper side and the lower side of the detecting coil 53, the

induced voltage is generated in the detecting coil 53 by variation of the electric current passing through the electromagnetic coils 50a and 50b. Fig. 9 includes a graph of the induced voltage of the detecting coil 53, which is influenced by variation of the electric current passing through the electromagnetic coils 50a and 50b. Immediately after changing magnetizing directions of the electromagnetic coils 50a and 50b, the variation of the electric current with respect to time is great, so the induced voltage of the detecting coil 53 is highly influenced. Thus, when the variation of the electric current passing through the electromagnetic coils 50a and 50b is small or the induced voltage generated by the reciprocating motion of the moving member 10 is on the minus side of Fig. 9, a threshold voltage value is applied to the induced voltage (parts "A" and "B" of Fig. 9) so as to restrict the influence of the variation of the electric current passing through the electromagnetic coils 50a and 50b. In Fig. 9, if the variation of the electric current passing through the electromagnetic coils 50a and 50b is great in the parts "A" and "B", average induced voltage of the parts "A" and "B" may be calculated, pulse widths of the parts "A" and "B" and average width thereof may be calculated, and frequency component of the induced voltage of the detecting coil 53 (twice as high as the frequency of the reciprocating motion of the moving member 10) may be solely detected.

In Fig. 9, the frequency of the induced voltage of the detecting coil 53 is twice as high as the frequency of the reciprocating motion of the moving member 10, but they may be equal as shown in Fig. 10. Peaks of the induced voltage of the detecting coil 53 appear in parts "C" and "D", but they are equally influenced by the variation of the electric current passing through the electromagnetic coils 50a and 50b, so it is difficult to detect if the reciprocating motion of the moving member 10 is proper or not. Therefore, if the frequency of the induced voltage of the detecting coil 53 is twice as high as the frequency of the reciprocating motion of the moving member 10, it is easy to detect if the reciprocating motion of the moving member 10 is proper or not.

In the electromagnetic pump shown in Fig. 1, the inlet paths 38a and 38b, which are respectively formed on the both sides of the moving member 10, are connected, and the outlet paths 40a and 40b, which are respectively formed on the both sides of the moving member 10, are connected, so the paths are connected in parallel; in another embodiment, paths of a plurality of electromagnetic pumps may be serially connected. In this case, the outlet path 40a may be connected to the inlet path 38b, or the outlet path 40b may be connected to the inlet path 38a.